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ROLL DAMPING MOMENT MEASUREMENTS FOR THE BASIC FINNER AT SUBSONIC AND SUPERSONIC SPEEDS

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U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

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Aerodynamics Research Report 59

ROLL DAMPING MOMENT MEASUREMENTS FOR THE BASIC FINNER AT SUBSONIC AND SUPERSONIC SPEEDS

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ABSTRACT: Wind tunnel measurements are presented of the aerodynamic roll damping moment coefficient derivative of the Basic Finner configuration. Data were obtained over the Mach number range from 0.22 to 4.81. At four Mach numbers the roll damping moment coefficient derivatives were measured as a function of angle of attack with roll rate as a parameter. A "free decay" technique was used to obtain the data. The present results compare favorably with free flight ballistics range data.

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This investigation was performed at the request of the Bureau of Naval Weapons under Task Number RMMO-42-005/212-1/F008-09-001.

These tests were conducted for the dual purpose of checking out the test apparatus and to further define the roll damping moment characteristics of the Basic Finner configuration.

The author wishes to acknowledge the work of Mr. I. Shantz, under whose direction this program was started, Mrs. V. L. Schermerhorn, who conducted some of the tests, and Mr. R. T. Groves, under whose direction the data reduction was started.

R. E. ODENING
Captain, USN
Commander

K. R. ENKENHUS
By direction

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INTRODUCTION

Roll damping moment measurements may be obtained either from free flight tests in a ballistic range or from forced or free spin tests in a wind tunnel. Generally, ballistic range tests are restricted to small yaw angles. In contrast, the test apparatus used in this investigation permits making roll damping moment measurements for angles of attack up to tunnel blockage limits. For subsonic, transonic, and supersonic speeds, angles of attack of 90, 10 and 25 degrees, respectively, were considered the practical limit for the size model used in this investigation.

Using the spin decay test technique roll damping moment coefficients were obtained for zero degrees angle of attack at two subsonic Mach numbers, 0.22 and 0.77, and at eight supersonic Mach numbers in the range 1.53 through 4.81. Effect of angle of attack was obtained at Mach numbers 0.22, 0.77, 2.54 and 4.10.

SYMBOLS

A_p panel area of fin

b fin span

C_{ℓ_δ} roll moment coefficient derivative due to fin cant, $\dfrac{\partial C_\ell}{\partial \delta}$

C_{ℓ_p} roll damping moment coefficient derivative due to rolling velocity, $\dfrac{\partial C_\ell}{\partial\left(\frac{pb}{2V}\right)}$

C_ℓ roll moment coefficient, $\dfrac{L}{qA_p bn}$

d diameter of body, one caliber

L rolling moment

$L_\delta \delta$	rolling moment due to angle of cant
$L_p p$	rolling moment due to aerodynamic damping
I_x	axial moment of inertia
M	Mach number
n	total number of fins
p	rolling velocity
q	free-stream dynamic pressure
$\left(\frac{pb}{2V}\right)$	spin parameter
t	time
V	free-stream air velocity
α	angle of attack
δ	angle of fin cant
ρ	free-stream air density
φ	roll displacement
$\dot{\varphi}$	roll velocity, p
$\ddot{\varphi}$	roll acceleration, $\dot{p}$

Subscripts

o	initial conditions
ss	steady state

MODEL DESCRIPTION AND TEST TECHNIQUE

The Basic Finner configuration (Figure 1) consists of a cone cylinder with four rectangular fins mounted in a cruci form arrangement. Overall model length is ten calibers, the

cone half angle is ten degrees, and the fins are one caliber in chord with an overall span of three calibers.

The roll damping moment data were obtained by employing a spin decay technique. This technique consists of driving a sting-mounted model up to the required spin rate, disengaging the drive, and continuously recording the spin rate as a function of time. The significant features of the test apparatus are labeled in the photograph of Figure 2. Air at 100-250 psi enters the sliding vane air motor through the indicated coupling. The exhaust air exits from the rear of the motor through axial ducts. The magnetic clutch connects the air motor to model sting unit. This unit is supported by two tandem bearings. Signals from the photo transistor-type tachometer come through leads just below the tachometer unit. These leads also carry the release signal to the magnetic clutch. The bearing housing is constructed so that the bearings may be replaced easily when poor repeatability of the vacuum tare readings indicates excessive bearing wear. The entire unit is positioned in angle of attack through a worm gear drive to the sector support. Model angle of attack is set to within one minute of arc from the tunnel operator's control console.

Upon clutch release the rotating portion of the system consists of the model and that portion of the sting support upstream of the clutch. Both sting and model must be used in the moment of inertia measurement. Although a portion of the sting (cylindrical shaft) as well as the model is rotating, the aerodynamic roll damping contribution of the sting is neglected.

DATA REDUCTION TECHNIQUE

Both the roll damping moment and the rolling moment due to fin cant are found from the spin decay history. This is accomplished by equating the rate of change of angular momentum to the applied moments. The mathematical expression for the spin decay is:

$$I_x \dot{p} = L_\delta \delta + L_p p \qquad (1)$$

I_x is the total moment of inertia of the model-sting combination about the axis of rotation, $L_\delta \delta$ the roll moment induced by fin cant, and $L_p p$ the roll damping moment. The solution of (1) is:

$$p + \frac{L_\delta \delta}{L_p} = \left(p_o + \frac{L_\delta \delta}{L_p} \right) e^{\frac{L_p}{I_x}(t - t_o)} \tag{2}$$

In equation (2) the initial conditions are $p = p_o$ when $t = t_o$. The steady state roll condition may be defined as $\dot{p} = o$, $p = p_{ss}$. Inserting into equation (1) and solving for p_{ss} gives $p_{ss} = -(L_\delta / L_p)\delta$.

The definition of the roll damping moment coefficient derivative, C_{ℓ_p}, and the rolling moment coefficient derivative due to fin cant, C_{ℓ_δ} is respectively:

$$C_{\ell_p} = \frac{\partial C_\ell}{\partial \left(\frac{pb}{2V} \right)} = \frac{L_p}{\left(\frac{b}{2V} \right) b q_\infty A_p}$$

$$C_{\ell_\delta} = \frac{\partial C_\ell}{\partial \delta} = \frac{L_\delta}{b q_\infty A_p}$$

Inserting the steady state roll relationship $p_{ss} = -(L_\delta / L_p)\delta$ into equation (2), solving for L_p and writing in coefficient form gives:

$$C_{\ell_p} = -\frac{I_x}{t - t_o} \left(\frac{2V}{q_\infty A_p b^2} \right) \ln \left(\frac{p_o - p_{ss}}{p - p_{ss}} \right) \tag{3a}$$

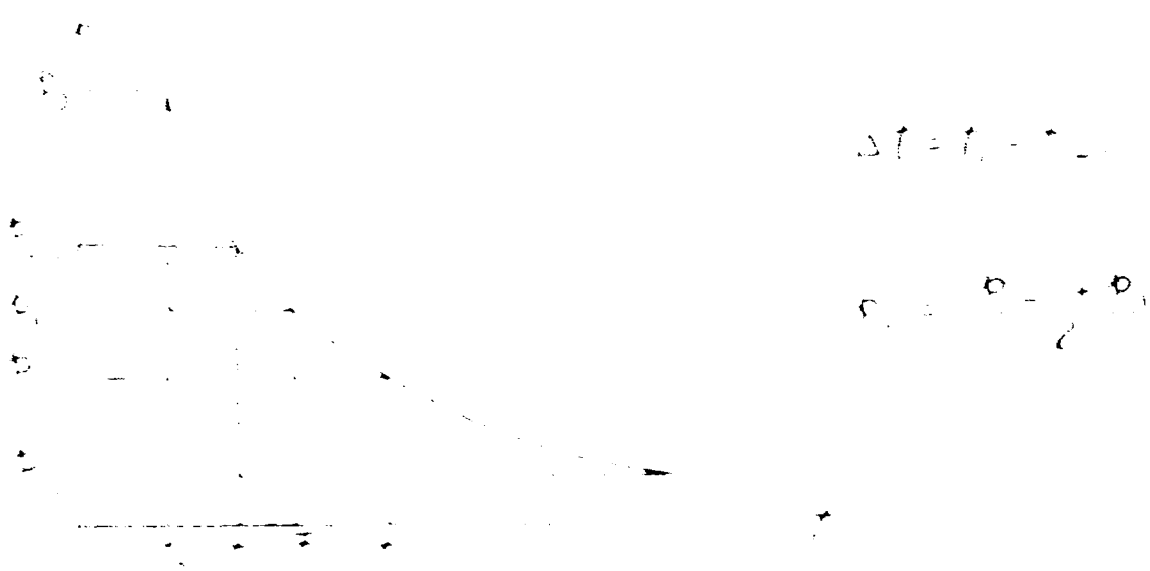
Again, using the steady roll relationship and the above definition of C_{ℓ_δ} gives:

$$C_{\ell_\delta} = -\frac{2p_{ss}}{\delta}\left(\frac{b}{2V}\right)C_{\ell_p} \tag{3b}$$

Thus, it may be seen that both coefficient derivatives C_{ℓ_p} and C_{ℓ_δ} may be calculated from measurable quantities.

Two assumptions have been made in the derivation. First, the roll damping is a linear phenomenon or equivalently that the coefficients in equation (1) are constants; secondly, there is no damping contribution due to bearing friction. Since neither of these assumptions is valid in practice, steps must be taken to modify the preceding analysis to account for the non-linear aerodynamics and bearing friction.

As Mach number, Reynolds number and angle of attack are known and invariant for each test run (see Table 1 for values) the only significant variation of the coefficients L_p and L_δ of equation (1) is with roll rate p. A quasi-linear method is used to find these functions. Essentially, this involves the assumption that the roll decay history is "piece-wise linear." The roll decay history is broken into n sub-intervals as depicted in the sketch below:



Over the ith sub-interval equation (1) is assumed to have constant coefficients with an initial spin rate of p_{i-1} and a final spin rate of p_i. Thus, in equations (3) p_{i-1}, p_i, t_{i-1}, t_i replace p_o, p, t_o, t to give:

$$C_{\ell_p}(\bar{p}_i) = -\frac{I_x}{(t_i - t_{i-1})}\left(\frac{2V}{q_\delta A_p b^2}\right)\ln\left(\frac{p_{i-1} - p_{ss}}{p_i - p_{ss}}\right) \tag{4a}$$

$$C_{\ell_\delta}(\bar{p}_i) = \frac{p_{ss}}{\delta}\left(\frac{b}{2V}\right)C_{\ell_p}(\bar{p}_i) \tag{4b}$$

It will be noted in the above expressions that the coefficient derivatives C_{ℓ_p} and C_{ℓ_δ} are assigned to the average spin rate, $\bar{p}_i$, over the interval Δt for small intervals Δt. A plot of C_{ℓ_p} and C_{ℓ_δ} at points $\bar{p}_i$ is assumed continuous in roll rate p because of the continuity of the roll history and the fact that $\bar{p}_i = p(\bar{t}_1)$.

The second modification to the linear analysis accounts for bearing friction. The contribution of bearing friction is removed by obtaining two roll histories, one with the desired tunnel flow conditions established, and the second with the tunnel test section evacuated. The tacit assumption is then made that the decay mechanism during the vacuum test is due entirely to bearing friction and further that this bearing friction is identical to that which occurs during the spin decay under aerodynamic loads. Using the vacuum run as a tare, the value of C_{ℓ_p} measured under these conditions is subtracted from C_{ℓ_p} obtained during tunnel flow to give the net aerodynamic contribution. Vacuum tare readings are taken every fifth wind tunnel test to account for bearing wear.

DISCUSSION OF RESULTS

The Basic Finner configuration used for these tests had zero fin cant. Because of this only the roll damping moment coefficient derivative, C_{l_p}, was measured. Table 1 summarizes the test conditions. C_{l_p} was obtained as a function of angle of attack at two subsonic and two supersonic Mach numbers and at six additional supersonic Mach numbers at zero angle of attack only. The two subsonic Mach numbers were 0.22 and 0.77 for which the angle of attack range was -10.0 to +90.0 degrees and -10.0 to +10.0 degrees, respectively. The two supersonic Mach numbers were 2.54 and 4.10, for which the angle of attack range was -10.0 to 26.8 degrees and 0 to 22.0 degrees, respectively. Tunnel blockage limits fixed the angle of attack range.

The data obtained at Mach 0.22 (see Figure 3) were of particular interest for several reasons. C_{l_p} is strongly dependent on spin rate at angles of attack above 25 degrees. The data indicate that C_{l_p} is also strongly dependent on spin rate at zero degrees angle of attack. Some doubt was raised as to the validity of the test technique. However, this portion of the test was repeated using a modified turbine, tachometer and housing. Comparison of the repeat data with the original test data showed a difference of, at most, ±5 percent. In the angle of attack interval 0 to 10.0 degrees C_{l_p} increased with spin rate. In the interval 10.0 to 20.0 degrees C_{l_p} is essentially constant with small dependency upon spin rate. Above 20.0 degrees C_{l_p} shows a high dependency on spin rate and decreases in value irregularly with angle of attack. Although the test was conducted up to an angle of attack of 90 degrees, the damping effect of the fins above 60 degrees was of the same order as the bearing friction. Hence, the subtracting operation with respect to the tare readings previously described resulted in large scatter of the experimental data. For this reason only the data obtained at the

highest spin rate of 130 rps are shown above an angle of attack of 60 degrees.

Figure 4 gives the roll damping moment coefficient derivative, C_{ℓ_p}, versus angle of attack at a Mach number of 0.77. Tunnel blockage limited the angle of attack range from -10 to +10 degrees. These data have two characteristics in common with those obtained at Mach 0.22: a strong dependency on roll rate at zero degrees angle of attack and a significant increase with angle of attack up to 10 degrees.

Figures 5 and 6 present the roll damping moment coefficient derivative, C_{ℓ_p}, versus angle of attack at Mach numbers of 2.54 and 4.10, respectively. For a Mach number of 2.54 it will be noted immediately that up to an angle of attack of 10 degrees, C_{ℓ_p} increases less than 7 percent with increasing roll rate. With increasing angle of attack there is an increasing dependency upon roll rate. For a Mach number of 4.10, C_{ℓ_p} is independent of roll rate for the angle of attack range tested.

Measurements were also made of the roll damping moment coefficient derivative, C_{ℓ_p}, at zero degrees angle of attack at eight Mach numbers in the range 1.53 to 4.81. These data show no significant spin rate dependency. Therefore, at each Mach number an average C_{ℓ_p} was taken over the spin range of 50 to 100 rps in increments of 10 rps. Table 2, which summarizes this part of the test program, indicates how much this mean varies from extreme values. These average values of C_{ℓ_p} are plotted versus Mach number in Figure 7. Free flight test data from reference (b) are also plotted for purposes of comparison. The free flight data were obtained for small angles of yaw. The wind tunnel data at zero degrees angle of attack fell slightly below the free flight data. Examination of Figures 5 and 6 indicates that C_{ℓ_p} increases with yaw angle; thus, at

small angles of yaw the wind tunnel data would be in closer agreement with free flight data.

CONCLUDING REMARKS

The "free decay" technique used to obtain the roll damping moment coefficient derivatives presented in this report has been demonstrated to be most useful. Using this method the store of data on the Basic Finner has been significantly increased by defining the roll damping moment coefficient derivatives as a function of angle of attack. Further, the non-linearity of roll damping has been demonstrated by indicating the dependency of this coefficient on spin rate at certain conditions of Mach number and angle of attack.

REFERENCES

(1) "Aeroballistic Research Facilities," Naval Ordnance Laboratory Report No. 1233

(2) Nicolaides, J.D., and Bolz, R.E., "On the Pure Rolling Motion of Winged and/or Finned Missiles in Varying Supersonic Flight," Ballistic Research Laboratories Report No. 799

TABLE 1

ROLL DAMPING TEST SUMMARY WITH FREE-STREAM FLOW PARAMETERS

Mach No.	Angle of Attack (Degrees)	Dynamic Pressure (Lbs/in^2)	Reynolds No. Per ft x 10^6
0.22	-10.0 to +90.0	0.62	1.60
0.77	-10.0 to +10.0	4.05	3.92
1.53	0	6.05	4.50
2.03	0	5.05	3.75
2.27	0	4.35	3.35
2.54	-10.0 to +26.8	3.60	2.95
2.76	0	2.97	2.63
3.51	0	1.63	1.80
4.10	0 to 22.0	0.98	1.35
4.81	0	0.55	1.00

TABLE 2

SUMMARY OF SUPERSONIC ROLL DAMPING DATA
AT ZERO ANGLE OF ATTACK

Mach No.	Maximum C_{l_p} *	Minimum C_{l_p} *	Average C_{l_p} *
1.53	.535	.522	.532
2.03	.426	.412	.422
2.27	.397	.350	.371
2.54	.359	.340	.352
2.76	.328	.304	.315
3.51	.280	.257	.273
4.10	.259	.188	.219
4.81	.192	.167	.181

*In 50 to 150 rps range; measurements made at increments of 10 rps.

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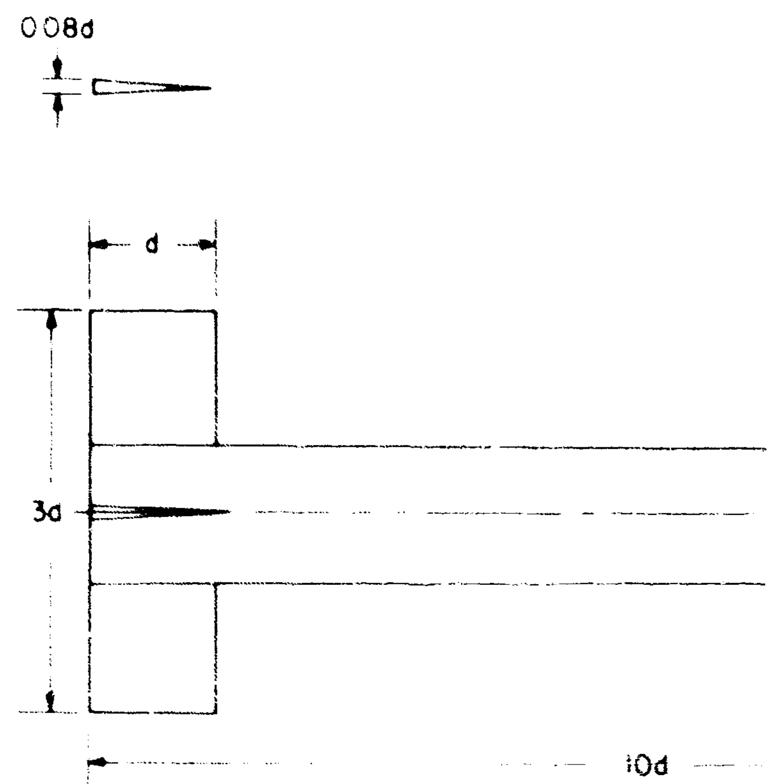
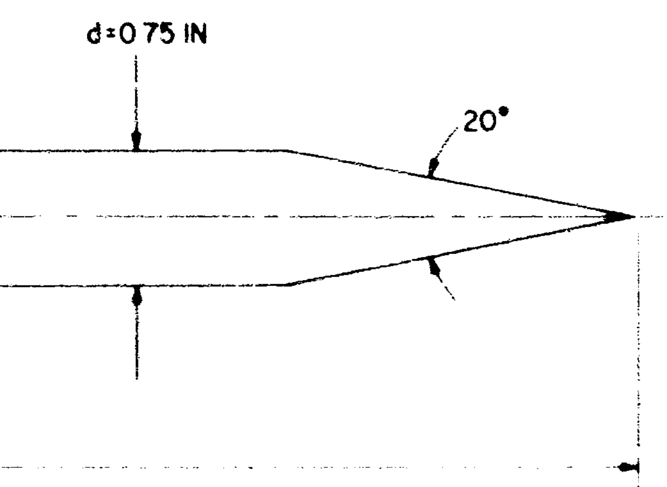


FIG I BASIC FINNE



NNER MODEL

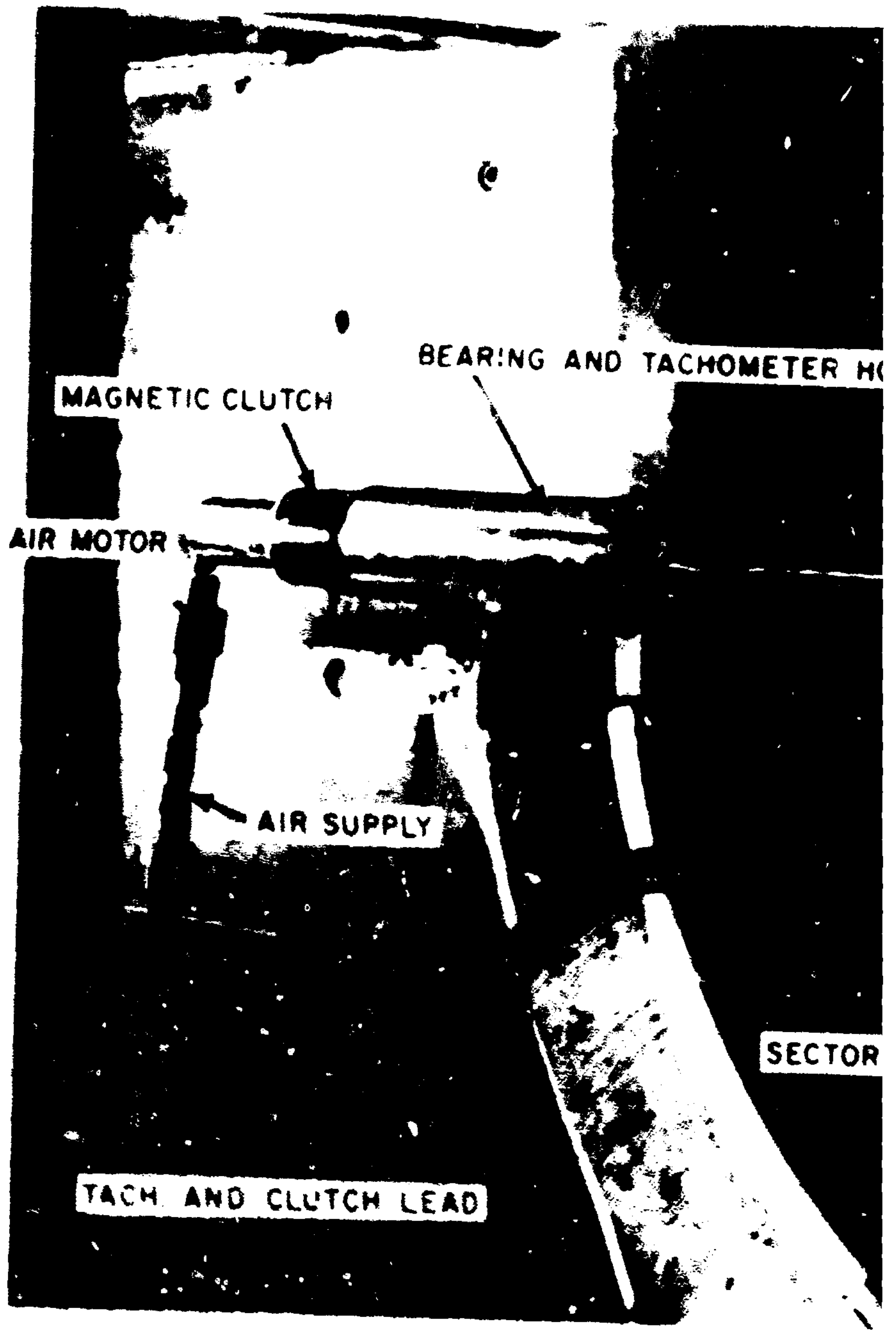


FIG. [illegible] BASIC FINNER MODEL MOU

OUNTED IN WIND TUNNEL

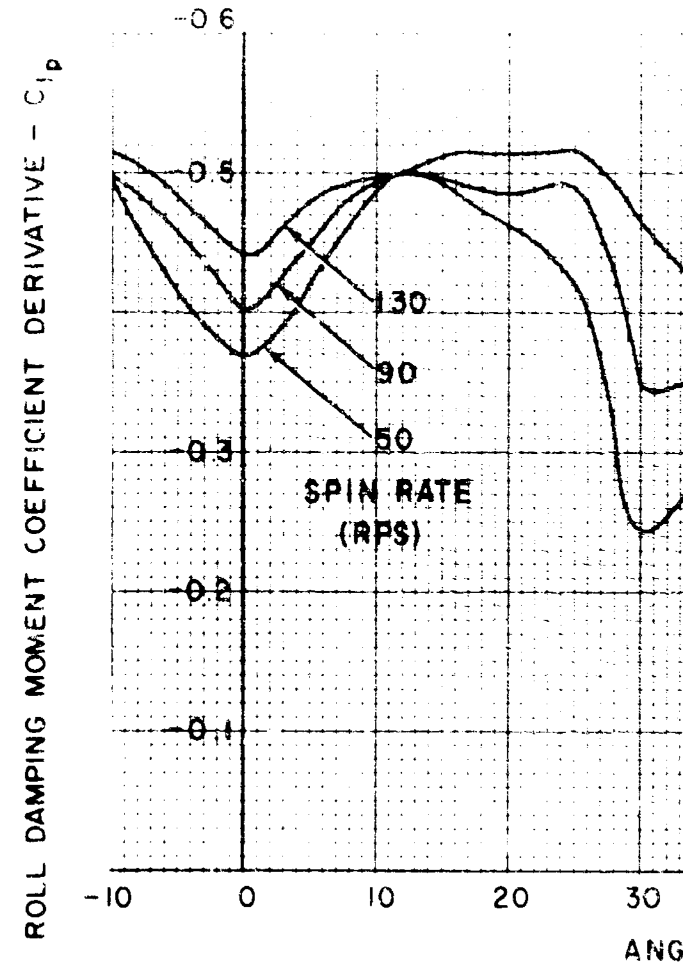
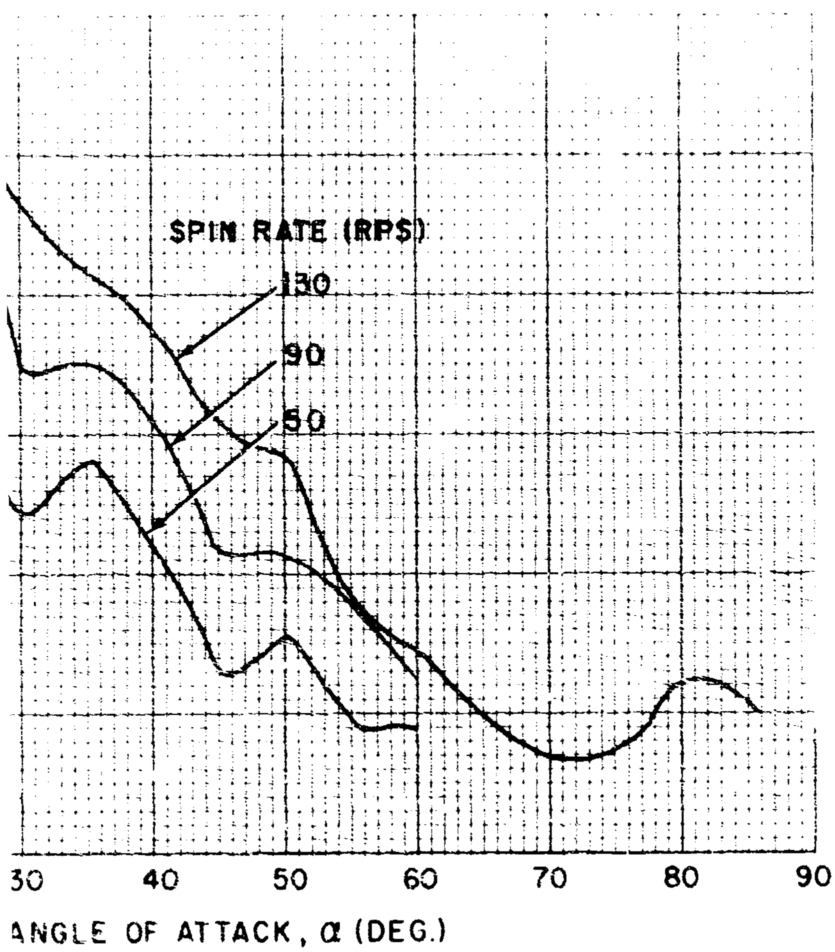


FIG. 3 EFFECT OF SPIN RATE AND

MOMENT COEFFICIENT DERIVA



ID ANGLE OF ATTACK ON ROLL DAMPING
RIVATIVE AT $M = 0.22$

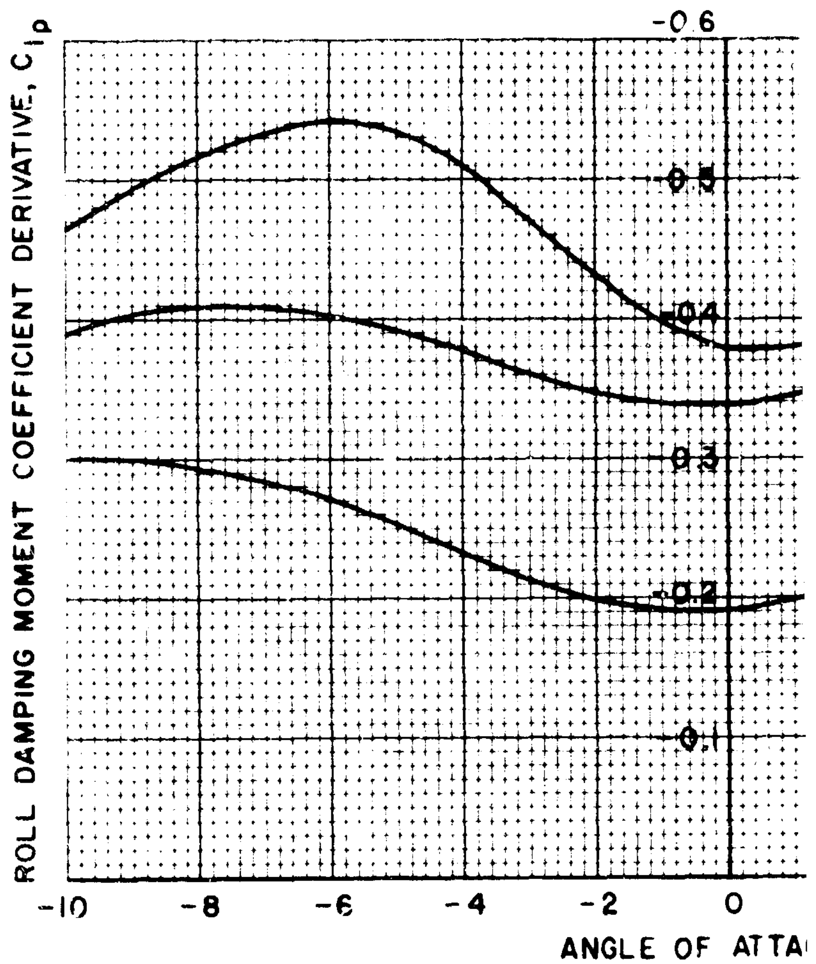
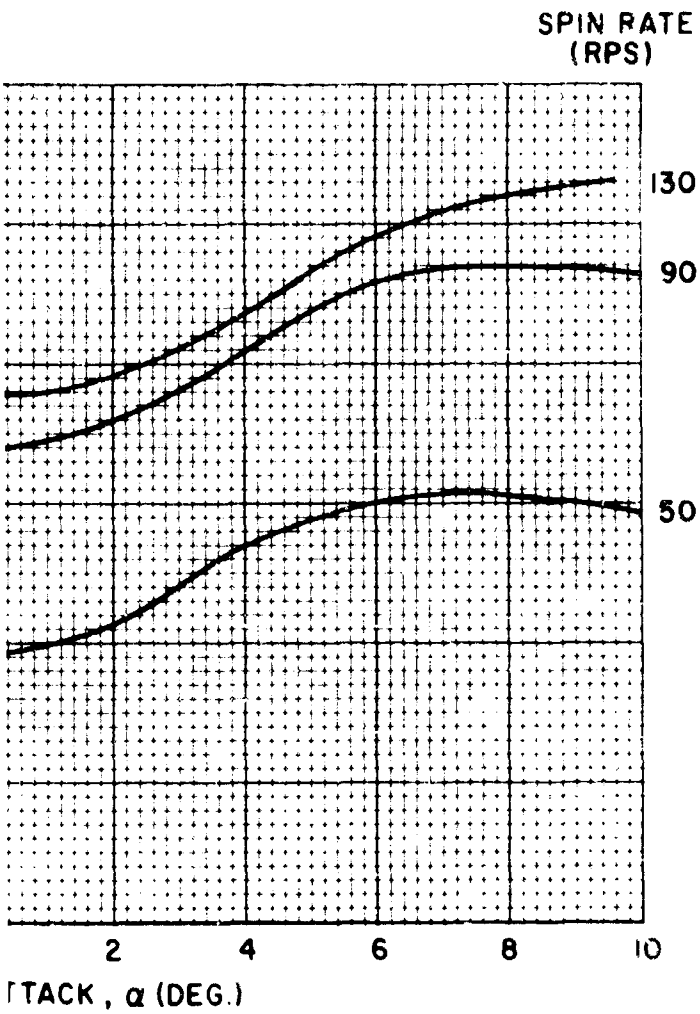


FIG. 4 EFFECT OF SPIN RATE AND ANGLE OF ATT
COEFFICIENT DERIVATIVE AT M = 0.77



ꞁTTACK ON ROLL DAMPING MOMENT

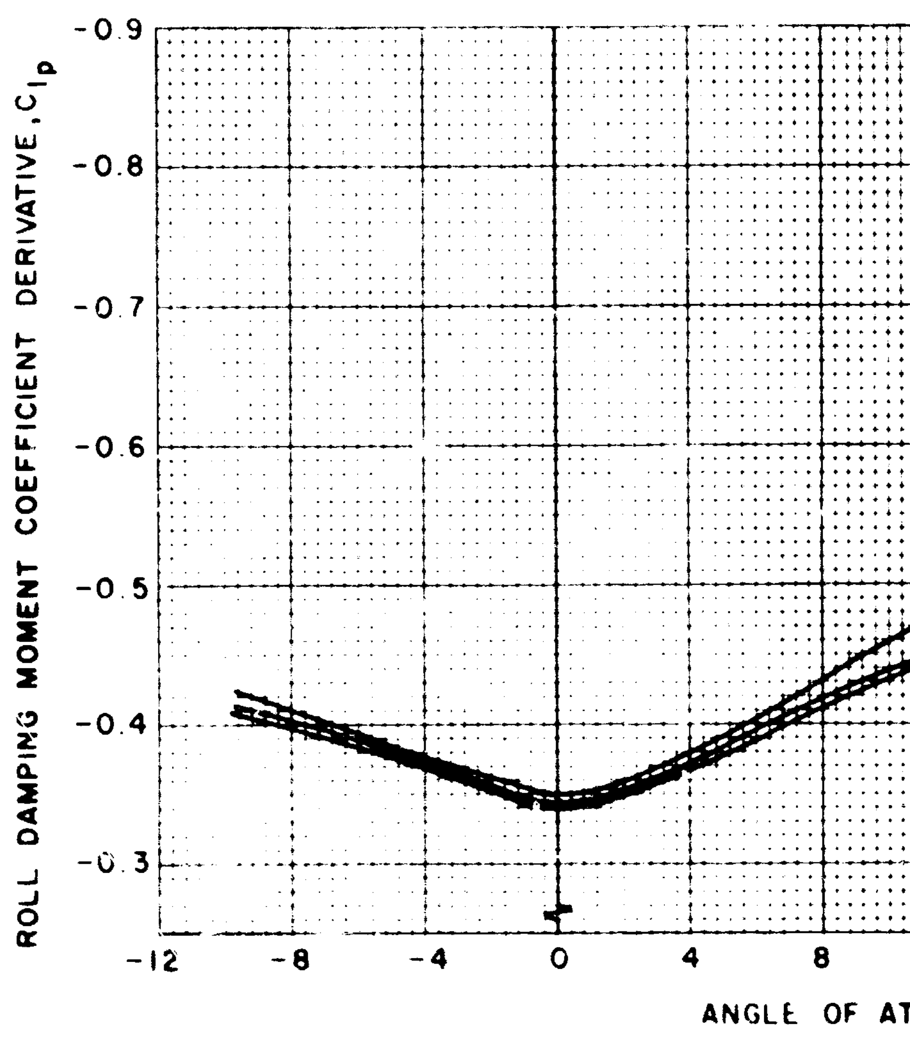
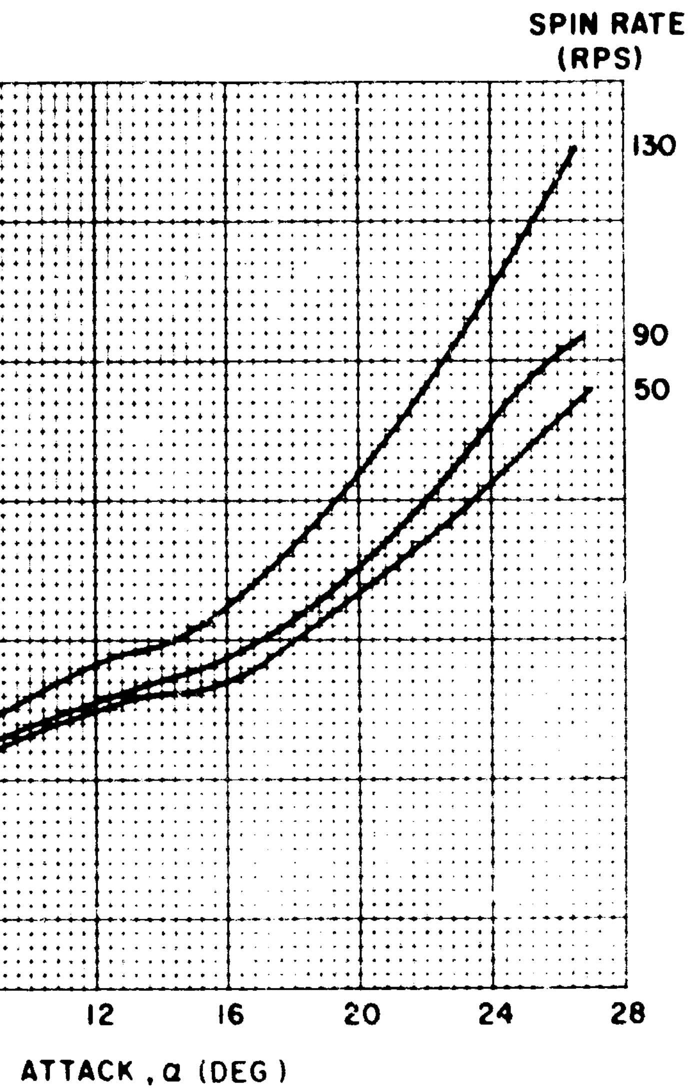


FIG. 5 EFFECT OF SPIN RATE AND ANGLE OF AT
COEFFICIENT DERIVATIVE AT M = 2.54



ATTACK ON ROLL DAMPING MOMENT

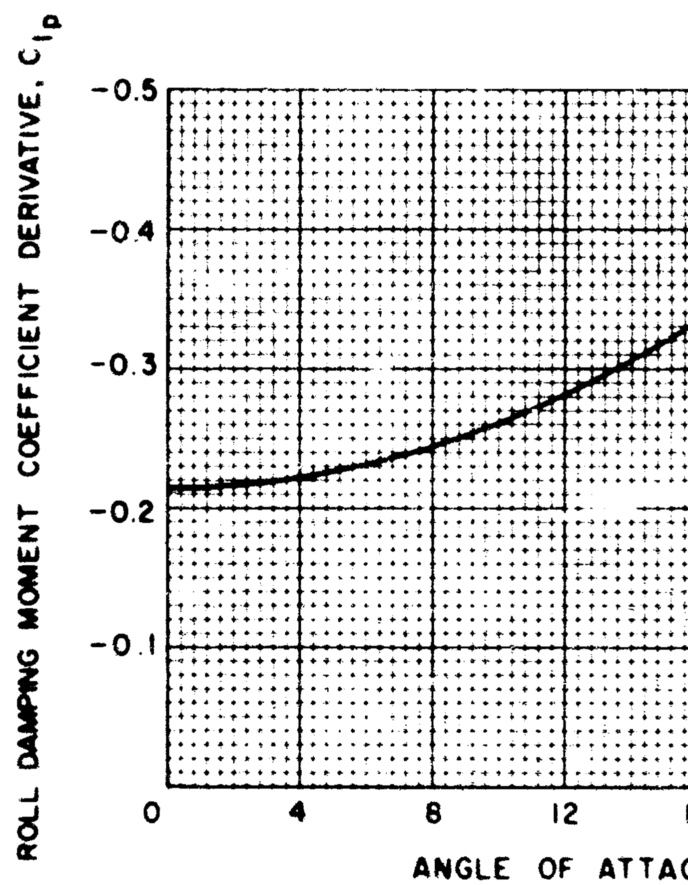
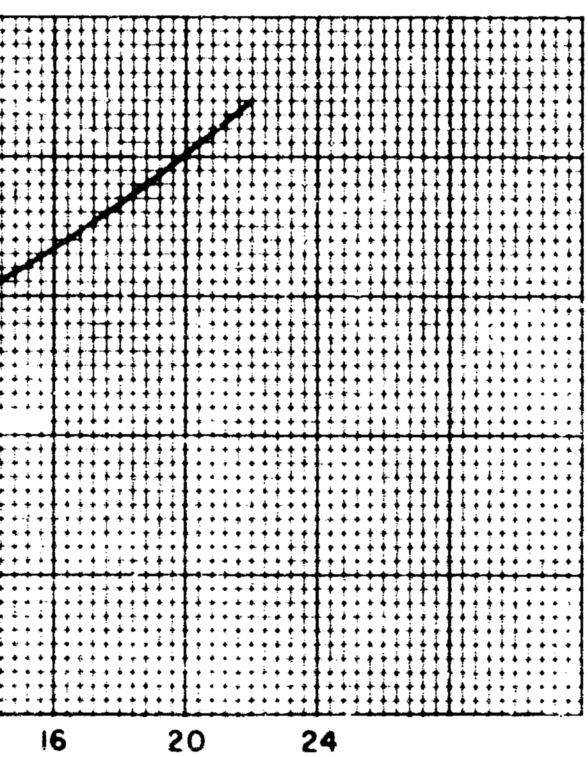


FIG 6 EFFECT OF ANGLE OF ATTAC
COEFFICIENT DERIVATIVE AT



TACK ON ROLL DAMPING MOMENT
AT M = 4.10

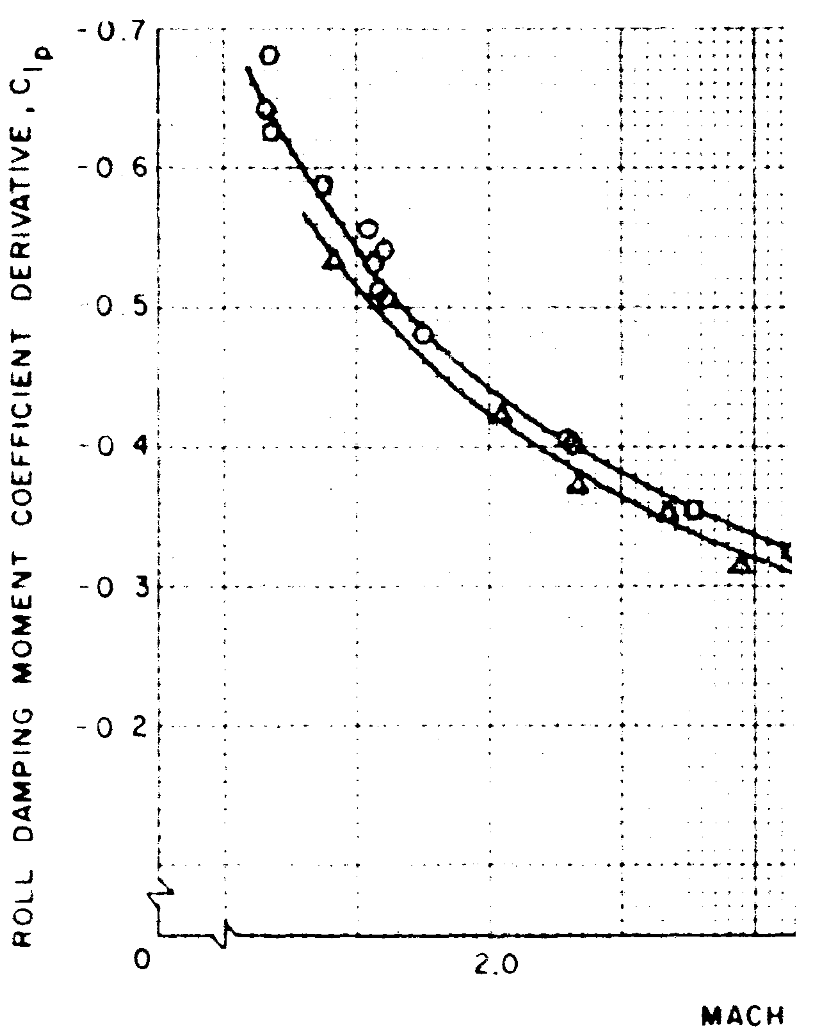
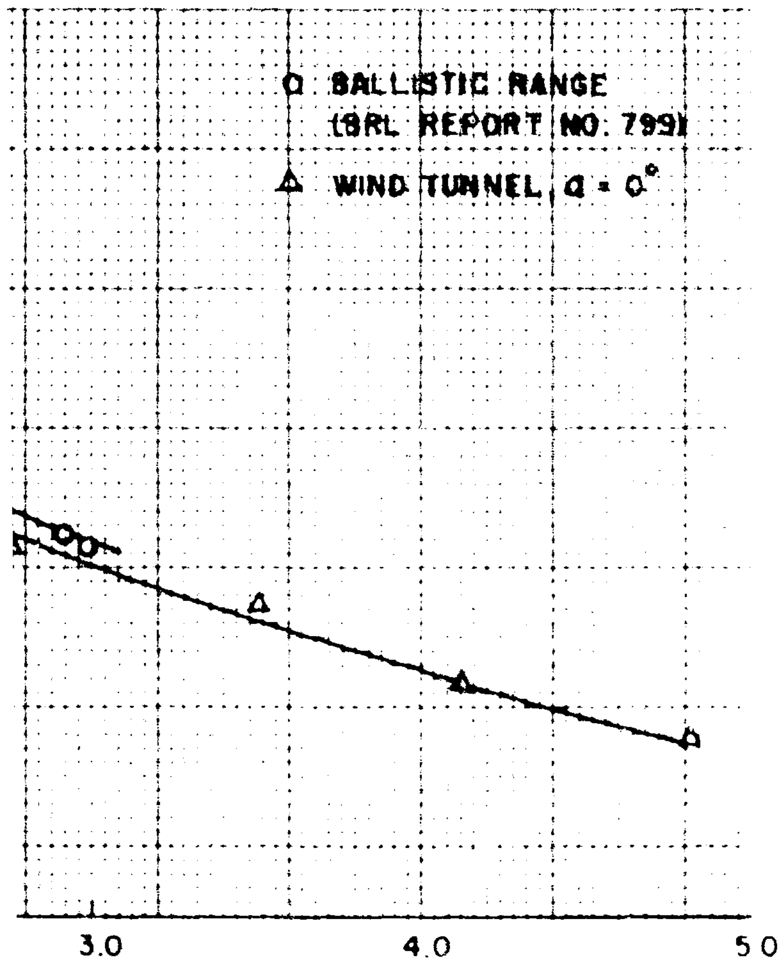


FIG 7 COMPARISON OF WIND TUNNEL AN
MOMENT COEFFICIENT DERIVATIVE



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AND BALLISTIC RANGE ROLL DAMPING
VE DATA